# How's your antenna?

Familiarity with antenna characteristics helps predict performance in matching the right 'stick' to the right application.

By Patrick E. Buller

To the casual observer, it's just a wire or just some sort of metallic nuisance that needs painting. We recognize it as an antenna, a metallic device, such as a rod or wire, for radiating or receiving radio waves. An antenna is most efficient when its physical length is appropriate for the frequency to be operated. The physical length is determined by its relation to *wavelength* (λ), which in turn is related to the speed of light.

The velocity of light, *V*, is roughly 186,000mi./s. Multiplying *V* by 5,280ft./mi. yields 984 × $10^8$ft./s. *Megahertz* is a million events per second. One wavelength is also one hertz, which is also equal to one period of events per second. Therefore, 984,000,000 divided by frequency equals one wavelength (1λ).

The difference in the light observed at the center of the parabolic beam and that of the bare bulb is *gain*

One wavelength = 984 ÷ *F*(MHz). For the ½λ dimension, in feet, 492 is the value to be divided by the frequency, and 492 ÷ *F*(MHz) = ½λ, in feet.

Example: 984 ÷ 155MHz = 6.35ft. = 1λ.

½λ = 3.175ft.

3.175ft. × 12 in./ft. = 38.1in.

¼λ = 19.05in.

All of the above is relative to the speed of light. If we are going to use wires or conductors of any type as the antenna, then things take on a different characteristic. Anything other than free space will slow down energy, and the ratio of free-space travel to conductor travel is the *velocity factor,* usually noted as *vp*.

The *isotropic* antenna is a fictitious antenna, also called the *point source*. It is analogous to a bare flashlight bulb theoretically illuminating a room evenly. When the flashlight bulb is placed at the focal point of a parabolic reflector, a light beam is formed. The difference in the light observed at the center of the parabolic beam and that of the bare bulb is *gain*. This comparison relates directly to microwave antennas that use a parabolic dish. In fact, microwave antennas are compared to the isotropic antenna, and all gains are written as units of *dBi,* meaning decibels relative to a hypothetical isotropic antenna.

By definition, the *dipole* antenna is a ½λ conductor, with energy supplied in the center, as shown in Figure 1 on page 49. It is a balanced-feed device, and its parameters are measured or compared at a height above ground of ¼λ. Its gain, compared to the isotropic antenna, is 2.15dBi. This antenna is easily built and calibrated, and it is the standard antenna for measurements of frequencies below 900MHz. Antennas with non-dBi gain figures are given in units of *dBd* (i.e., referenced to the dipole). Figure 2 on page 49 shows the voltage and current relationship of a ½λ dipole antenna.

Let's look at an antenna for its feed point impedance over several wavelengths. Keeping the physical length constant, the frequency will be changed and the base impedance measurements can be taken and the results plotted as shown in Figure 3 on page 49. A horizontal line that represents 0Ω resistance at the left and approaches infinity at the right represents the resistance. Inductive reactance lies above the horizontal line, and capacitive reactance lies below.

In the electronics world, we like to have everything resistive. So, looking at the spiral, we determine that if we operate at the point where the spiral line crosses the resistive line, the antenna would then be *resonant*. (The energy boys call this point *unity power factor*.)

So, is the free-space formula in error? Not really, it just needs some modification. In reality, the frequency that provided this zero reactive point was plugged into the formula to find a "K" factor that would modify the free-space formula, 492 ÷ *F*(MHz), to bring us to the zero point. That "K" factor is 0.95 for wire antennas up to about 30MHz. Beyond 30MHz, the diameter of the wire also affects the overall length for a pure resistive impedance. The result is the classic 468 ÷ *F*(MHz) seen in most text books for a ½λ antenna.

Figure 4 on page 50 shows the impedance spiral of a ½λ antenna cut to the dimensions of 468 ÷ *F*(MHz). Again, this is only good for wire antennas or thin elements for the lower frequencies and at ¼λ above ground. The lower the antenna is to ground, the lower this impedance will become. A rule of

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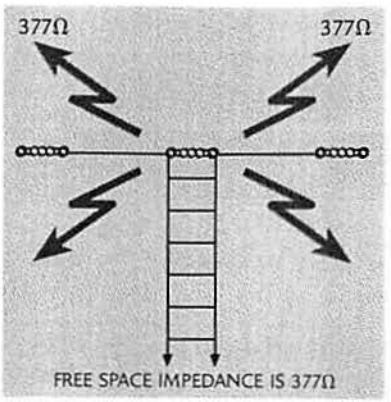


Figure 1. An antenna is a special case of a terminated transmission line.

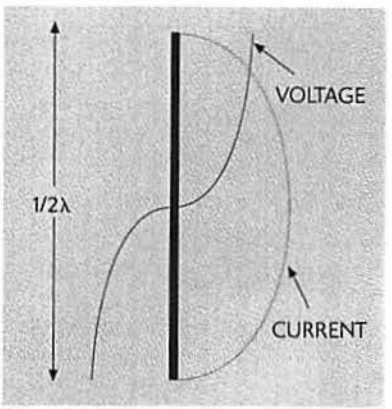


Figure 2. Voltage and current relationship of a ½λ antenna.

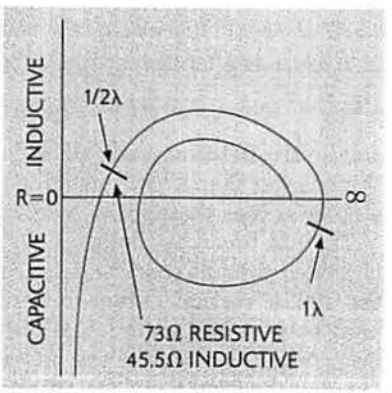


Figure 3. Impedance spiral of ½λ antenna. Free space dimension 492÷F(MHz).

thumb is if the antenna is about ⅛λ above ground, the impedance will measure somewhere around 50Ω. In the amateur radio band, this means an 80m antenna up 30' will closely match the magic number of 50Ω. Also note that the antenna has a higher impedance in the center if it is 1λ long. At ¾λ, the center impedance is again low. That means a center-fed antenna can and will operate on the 3rd harmonic. Examples would be a ½λ on 7MHz and a ¾λ on 21MHz.

Figure 5 on page 50 shows the impedance spiral of a ¼λ antenna cut for free-space dimensions. Note that the numbers are exactly one-half of the ½λ dipole: $Zo = 36 \times j21\Omega$. Again, the element must be shortened to yield pure resistance, using the same formula except ½ of the total length. The only difference between this antenna and the dipole is that the ground plane is considered infinite in length. In reality, it need only be ½λ diameter in all directions. The ¼λ antenna is a low-

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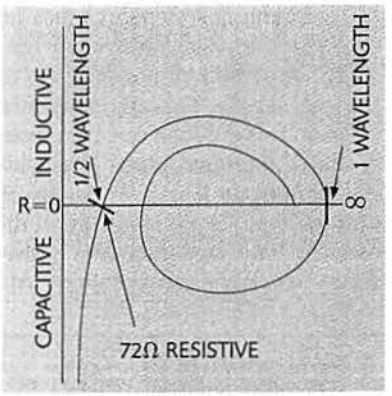


Figure 4. Impedance spiral of a ½λ antenna shortened by $K$=0.95 or length=468÷F(MHz).

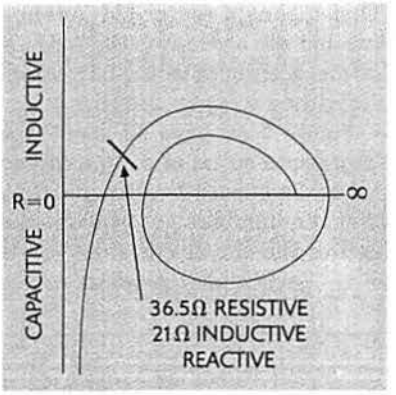


Figure 5. Impedance spiral of a ¼λ antenna free space dimension 492÷F(MHz).

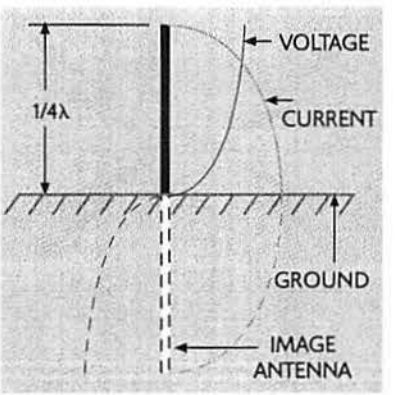


Figure 6. Voltage and current relationship of a ¼λ antenna.

impedance, or current-fed, antenna, as shown in Figure 6 above. It has a voltage minimum at the feed point and again at the ¾ point. Advantages of a ¾λ antenna are that the impedance can be near 60Ω (a better match than the ¼λ), and a minor lobe appears above the horizon, which is helpful with radiation to higher sites.

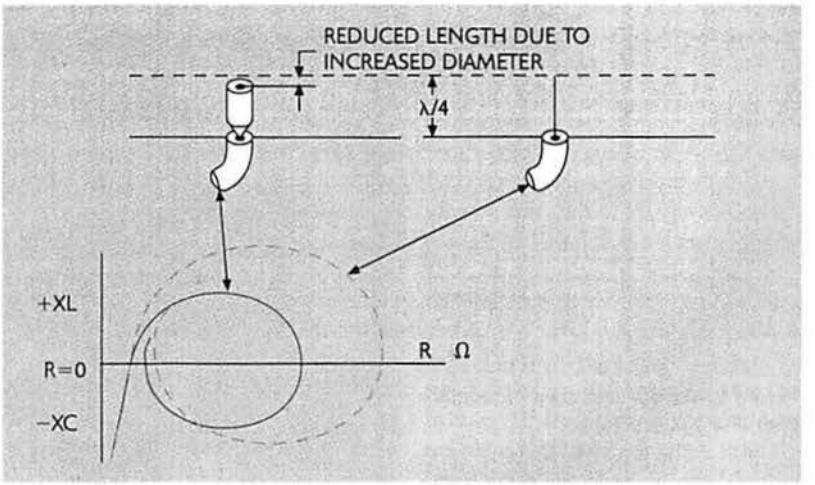


Figure 7. Impedance spiral of a λ/4 vertical antenna as a function of conductor diameter often referred to as *bandwidth*.

Figure 7 shown above amplifies another consideration of the radiating element. Large diameters lower the antenna's quality factor, or "Q." In other words, it makes it a broadband device. There is a larger spread of frequencies with which the antenna will operate with acceptable standing wave ratio. This is primarily due to the amount of capacity added because of the increased area. To keep the antenna resonant, the conducting element must be shortened to compensate for the added capacity. This brings the topic of the ratio of diameter of radiating element to wavelength dimensions, as shown in Figure 8 on page 51. In other words, the "K" factor is the determinate when the antenna element is larger than a small wire. In the case of VHF, anything larger than a ⅛ rod must use a K factor less than 0.95.

The AM broadcast industry first identified antenna characteristics in the 1920s. Vertical antennas were used because the radiation is uniform from the center of the tower. Dipole antennas have directivity, with nulls at the ends of the conductor. The broadcasters' interest was to obtain the most signal strength, so the vertical antenna underwent a series of tests to determine the optimum height. Figure 9 on page 51 graphs signal strength measured with different vertical antenna heights and 1kW of power. Note that maximum power is received with the antenna at 0.625λ, and almost nothing at one wavelength.

Figure 10 above graphs a side view of radiation with different

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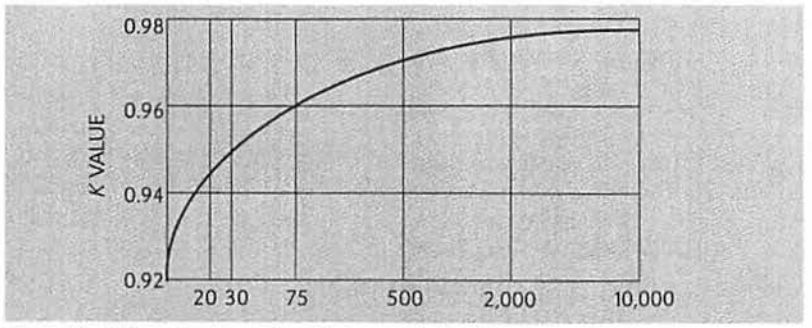



Figure 8. Ratio of halfwavelength to conductor diameter—same units.

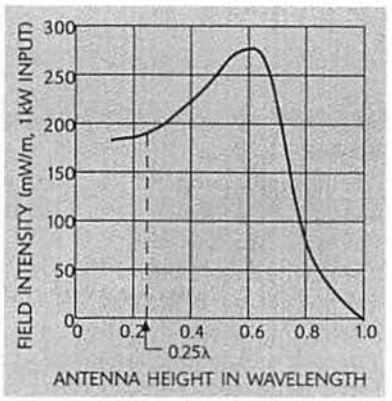



Figure 9. Plot of field strength vs. vertical antenna length.

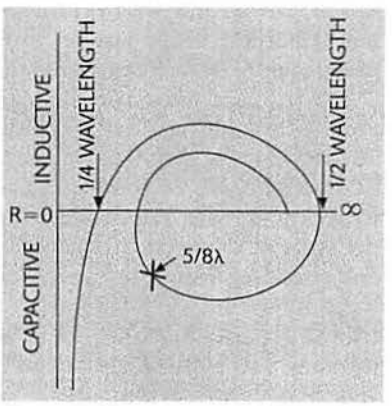



Figure 11. Impedance spiral of a vertical antenna. Note low resistance and capacitive reactance. Series inductance cancels. This is how the Larsen mobile $^{5}/_{8}\lambda$, 3dB gain antenna came about.

antenna heights. At the 5/8λ, you can see there is a minor lobe beginning at the 75° point, that gets somewhat larger at ¾λ (not shown). Installing a ¾λ antenna is an attractive prospect for vehicles because this antenna not only radiates in the horizontal but also has an elevated signal that can bounce off buildings. The ¾λ is particularly effective for motorcycle

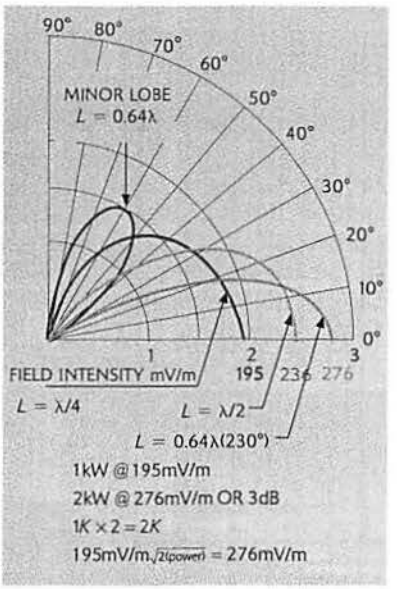


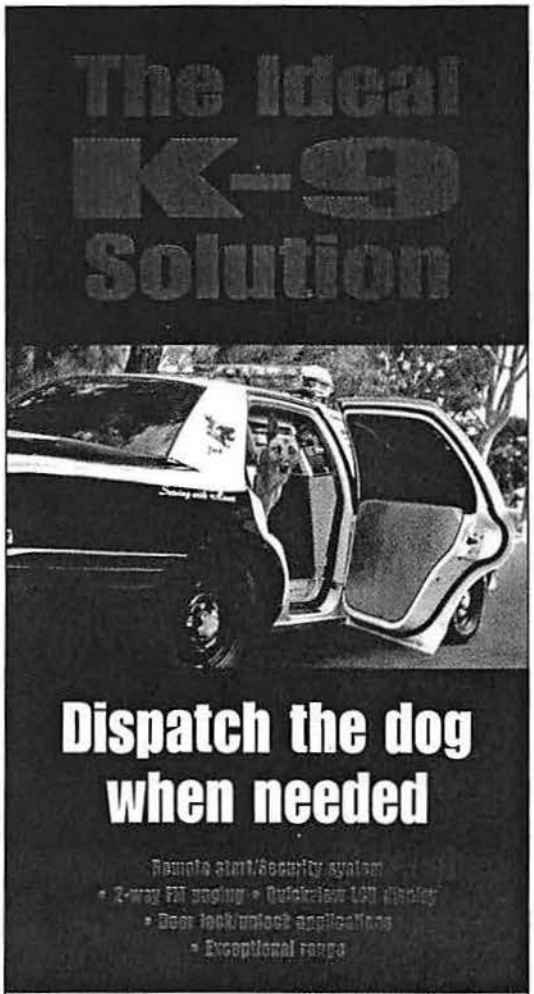

Figure 10. Vertical plane patterns for three values of antenna height. Field intensity is millivolts per meter.

radios using the VHF band. The impedance of a ¾λ vertical is closer to 50Ω than the ¼λ antenna.

The late James L. Larsen, founder of Larsen Antennas, introduced the $^{5}/_{8}\lambda$ antenna for mobile use by incorporating a coil at the feed point that cancels the capacitive reactance, leaving the antenna just above 50Ω resistive. It is marketed as the 3dB gain VHF antenna.

Another example of antenna impedance vs. height is shown in Figure 11 above. Any multiple of ½λ results in high impedance, sometimes referred to as *voltage feed*. Multiples of ¼λ are referred to as *current feed*.

It should be pointed out that even a small piece of wire is a high-impedance device, if it is measured with an ohmmeter. It is only low resistance when it's employed as a resonant device. ■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# How's your antenna?

Part II—The halfwave antenna is expanded into many other configurations, each having specific contributions to how RF energy is sent or received.

By Patrick E. Buller

In the past, antennas were generally used for fixed, single-frequency operations. Today's needs require antennas to have a much broader bandwidth to cover more frequencies. These new requirements include repeaters with wide frequency separation or the combining of more than two transmitters into one antenna.

One approach to increased bandwidth is the incorporation of larger-diameter material that lowers the antenna "Q" (discussed in Part I). Methods used to accomplish this incorporation include increasing conductor diameter or using more than one paralleled conductor. Parallel conductors define a circle that has the effect of a single conductor with a diameter equal to the spacing of the parallel conductors.

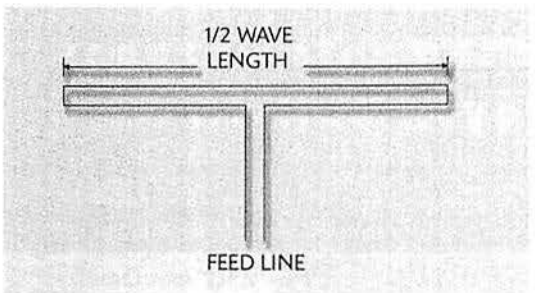


Figure 1. One halfwave antenna.

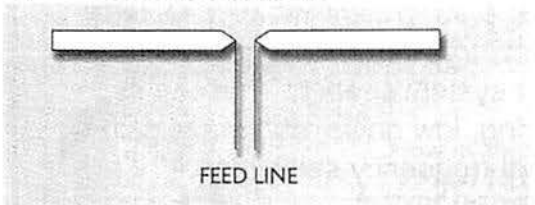


Figure 2. One halfwave antenna.

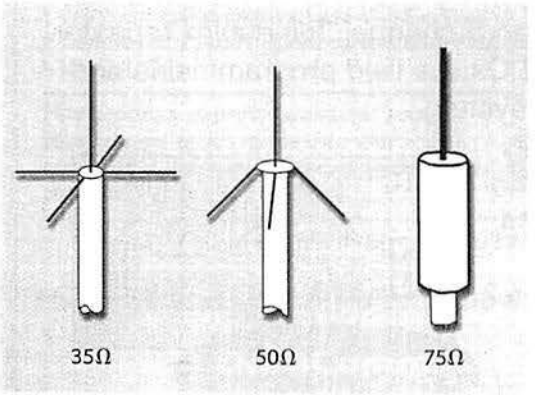


Figure 3. Impedance change by angle.

The bow tie antenna is another example of a large surface area that also increases bandwidth, often used in antennas for 450MHz and above. The folded conductor of a bow tie antenna also changes impedance.

### Impedance change

In a classic, folded dipole antenna, as shown in Figure 1 at the left, there are parallel conductors, but only one conductor is fed power. It raises the impedance of the feed point by the relationship of quantity of conductors, squared, times the antenna impedance. For example, a pair of wires $(2)^2 = 4 \times 72\Omega = 288\Omega$.

A three-conductor antenna raises the impedance nine times, providing all conductors are the same diameter. If diameters are equal, then spacing between wires and conductors is not a factor. If the diameters of the conductors are not the same, the spacing is indeed important.

If, instead of feeding only one of the two conductors, both conductors of each leg are made common, as shown in Figure 2 at the left, then the bandwidth is the same as the folded dipole, but the impedance is close to the classic 72Ω. Why the impedance difference? The folded dipole shares the current equally between the parallel wires; therefore the current in each wire is half that of a single conductor.

The folded dipole has several features that make it useful as a vertical collinear antenna. Besides increased bandwidth, wind loading is somewhat increased, but vibration is drastically reduced, which eliminates metal fatigue that is common in single elements of ground-plane antennas. Noise caused by particles whizzing past during high winds is reduced, and the lack of sharp points eliminates *corona noise*. Corona noise is observed by hearing a high-pitched squeal sounding like a siren with ever-changing pitch. Corona noise stops immediately after a lightning strike.

Impedance changes when different diameter conductors are part of the feed. The final impedance is a function of the ratio of diameters of each element and the spacing between conductors.

When comparing the impedance of a center-fed dipole of 72Ω to that of a ground-plane antenna of 36Ω, consider the geometry. The dipole is two conductors in the same plane, and the vertical antenna has one vertical, the other horizontal. Moving the horizontal element from horizontal down to about 40° raises the impedance to around 50Ω, which is valid for a single-element vertical antenna with a modified ground plane as shown in Figure 3 at the left.

### The collinear antenna

*Collinear* means having axes

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lying end to end in a straight line. Collinear antennas for the two-way radio market are usually made up in pairs. This is a gain of 3dB when one more element is added to a single element. For an additional 3dB, the two elements must be doubled, yielding four elements for a total antenna gain of 6dB.

The most common 6dBd vertical antenna for the 150MHz band consists of four halfwave rigid coax cable pieces fed at the bottom with an impedance-matching transformer enclosed in a fiberglass tube as shown in Figure 4 at the right. Note that the coax antenna elements have conductors changing positions between elements. All elements must have the same phase relationship for each element to contribute energy perpendicular to the elements. Therefore, it is necessary to have correct polarity. Remember that the phase changes 180° in halfwavelength. If the polarity were not changed, and elements were not transposed, the antenna would be two wavelengths long. No energy would radiate perpendicular to the elements, meaning no signal on the horizontal—just a four-leaf clover pattern with no radiation broadside or off the ends. In reality, the coax linear is not a true 6dBd but about 5.4dBd because of the uneven power distribution. The bottom element has to feed the other three, and the top element feeds none.

Another common antenna in the two-way industry is the folded dipole array. It is fed with equal lengths of coax cable, which allows energy to arrive at all antenna elements at the same time. Figure 5 at the right shows a cable arrangement that is not only acting as a phasing harness but is impedance matching as well. Quarterwave transmission lines will also perform as transformers. The advantage of this type of antenna, compared with the coax collinear, is each element is fed the same amount of power and its gain is near the full 6dBd. Arranging the elements around the vertical support can modify the radiation pattern. This option is not available with the coax collinear antenna.

### Downtilt

Collinear VHF antennas with a 12° beamwidth that are installed in high elevations do not cover nearby low elevations. In short, these antennas talk well mountaintop-to-mountaintop, but not down to the highway, where they are needed. *Downtilt* is when the beam is electrically lowered below the horizontal plane. This is done by a phase shift of power between each radiating element. This phase difference between elements forces the beam down from the horizontal.

Figure 6 on page 38 shows the phasing required for downtilt. Each element going in the vertical direction has leading phase from the lower element. The downtilt is limited to about 6°. Beyond this limit, side lobes appear that defeat the goal of downtilt and gain.

### Phased arrays

A single antenna has a definite gain. Duplicating this antenna and feed from the same source will provide 3dB more gain. Duplicating again will add 3dB more. The collinear antenna is one example of *phased array*. In the classic *broadside phased array* as shown in Figure 7 on page 38, eight dipole antennas are connected to a transmission line. Note that the transmission line is transposed. To have the antenna appear as one large antenna, all elements need to be fed with the exact same phase. For example, assume all elements will have the left side instantaneously positive. Each antenna is spaced halfwave apart, therefore the transmission line is transposed because the energy is shifted 180° in the halfwave transmission line. The center transmission line, however, is not transposed because the energy being fed in the center arrives at each antenna at the same time. If the antenna array were fed from the bottom, the center phasing harness would have a transposition.

The key in any phased array is keeping all elements in the correct phase relationship. Antenna patterns can also be shaped by changing the spacing of antenna elements and different feed phase angles.

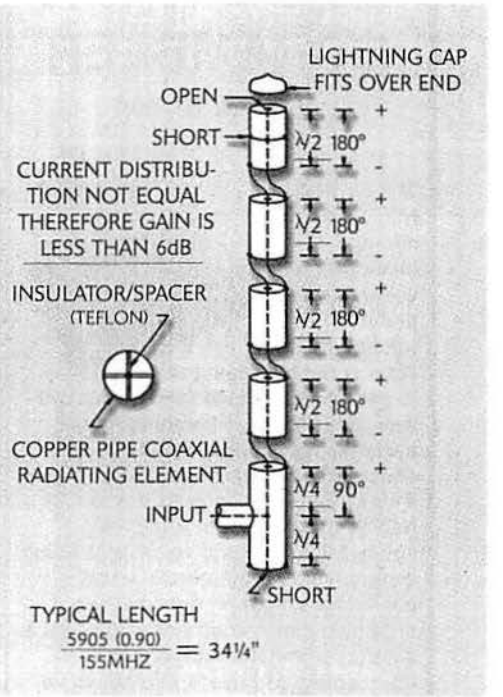


Figure 4. End fire collinear antenna.

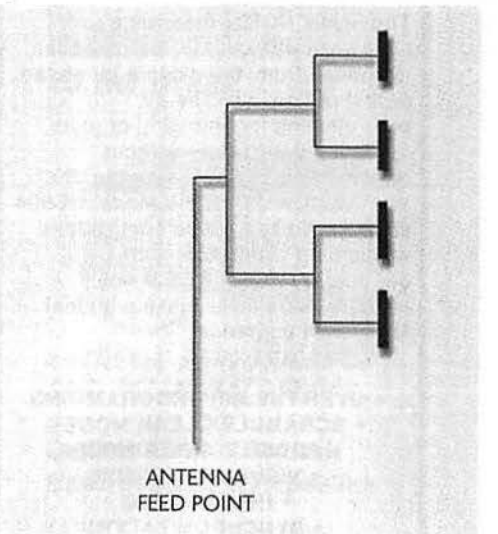


Figure 5. The collinear.

### Log periodic antennas

A log-periodic antenna, (as shown in Figure 8 on page 39) is a variation of the broadside antenna. The radiating elements decrease in length according to the logarithmic function. The design is based on

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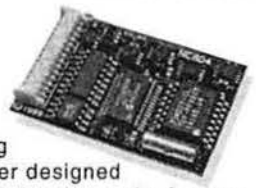

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antenna characteristics that are periodic with the logarithm of the frequency. The variation of the characteristics is small over a single time period, allowing the antenna to operate frequency-independent. In other words, it has an acceptable VSWR over a 2:1 frequency change—the detracting feature is that it has less gain than a Yagi-Uda antenna having the same number of elements, but it is less susceptible to ice buildup. Note the phase reversal of the feed line at each element.

### Parasitic array

The multi-element Yagi-Uda antenna was described by S. Uda in Japanese and subsequently in English by H. Yagi. It became first known in the United States as the yagi antenna. A three-element antenna is shown in Figure 9 on page 40 with optimum spacing for forward gain. The longer element is the reflector, and the driven element (that takes power) and the director are shorter. The driven element is the base where all elements are derived from. Its length is found by $492(K)/F(MHz)$, where $K$ is the ratio of diameter to wavelength. The reflector is 5% longer and the director is 5% shorter than the driven element. Optimum spacing is 0.2 wavelengths from reflector to driven element and 0.1 to 0.15 wavelengths between the driven element and the director. A single reflector is all that is required, but additional directors can be added for more gain. Some antennas may have as many as 48 directors, but the contribution of any more than a dozen is so small, it is best to add another full antenna and feed it in phase. The exception would be when insufficient real estate exists to add antennas side by side.

The operation of a Yagi-Uda antenna is based on all elements accepting energy from the driven element and re-radiating in the correct time relationship. Consider a single wave radiating from the driven element. The reflector receives this energy, and it begins to radiate. It does so in the correct time relationship to be in phase with the next wave produced by the driven element. The same contribution is experienced for the directors. They all add in-phase in the forward direction but add out-of-phase in the reverse direction. Anything that modifies the phase relationship directly affects the forward gain and its *front-to-back ratio*. Front-to-back ratio is the energy sent in the forward direction compared to that measured at 180°, and it is expressed in decibels. Ice buildup is one of many factors that alters the performance of the antenna. To make a Yagi-Uda antenna broadband, use large diameter elements, and no more than five. The more directors used, the higher the

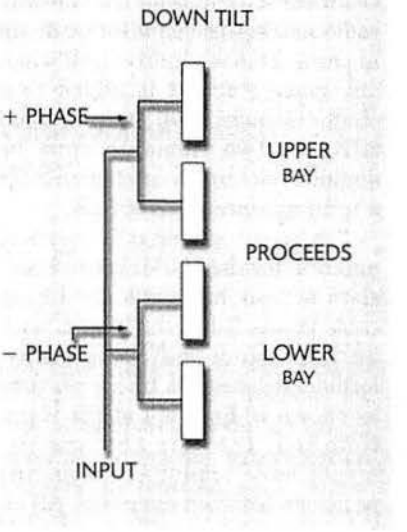


Figure 6. Downtilt.

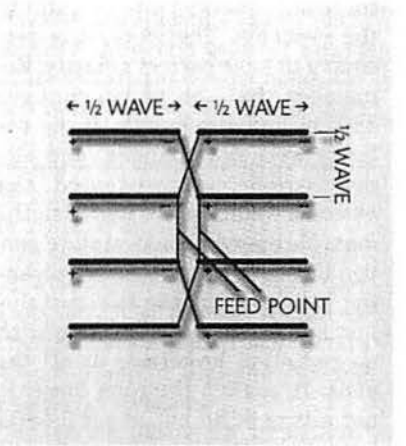


Figure 7. Broadside array.

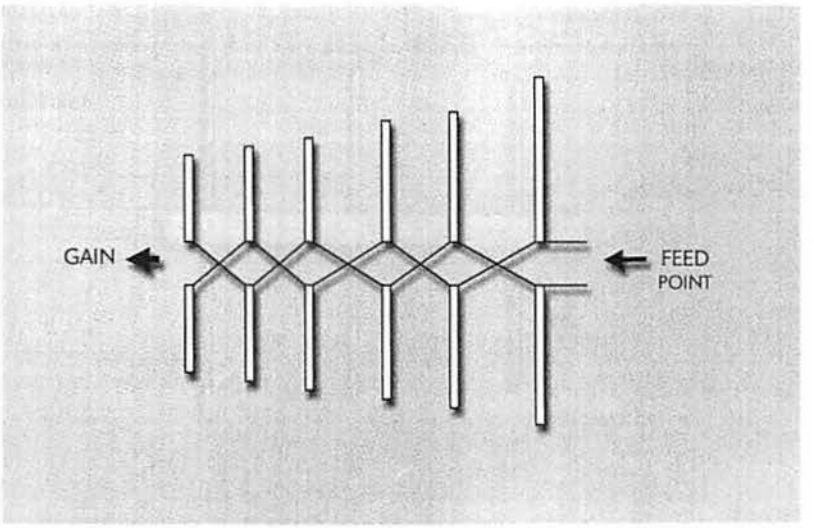


Figure 8. Log periodic antenna.

antenna Q is, resulting in less bandwidth.

**Slot antennas**

A *slot antenna* is the conjugate of a wire antenna. Figure 10 on page 40 shows a large conductive sheet where a halfwavelength section of material is cut out. The material removed is a half-dipole antenna. The slot, then, is a halfwave antenna, but with reverse properties. Its high impedance point is in the center compared to the dipole with the lowest impedance at the center. Polarization is vertical, and it is a balanced antenna.

When the antenna is rotated to where the slot is vertical, it is now radiating horizontal. Gain is achieved by stacking several in the vertical plane, one above the other. This antenna is the workhorse for the TV broadcast band. It is immune to lightning because its feed point is inside a grounded structure. Another use for the slot antenna is with guided missiles, aircraft and counterintelligence operations where the metal skin of the vehicle is used as the antenna. The slot is filled in with nonconductive resin, painted and completely camouflaged. If the slot antenna is backed with a cavity, it becomes highly directional and does not radiate inside the vehicle. Some texts incorrectly refer to this product as a "pylon antenna."

**Parabolic antennas**

Figure 11 on page 40 shows a parabolic antenna. It behaves identical to the flashlight. A source of energy at the focal point is re-radiated in the forward direction. The focal point can consist of a simple two-element Yagi-Uda antenna, a horn or an inverse parabolic antenna fed from the center of the larger antenna. The latter is common in space research antennas. For point-to-point microwave, the first two "illuminators" are common. Gain is calculated as $G=20\log D + 20\log F - 52.5$, where $D$ is diameter in feet and $F$ is in megahertz. The industry classifies this antenna at 55% efficiency. If a radome is installed, then the gain figure must be reduced to account for the radome loss.

If high-performance antennas are required, a shroud with RF absorbing material is added around the dish to attenuate most of the sidelobe energy and to improve the front-to-back ratio. To the observer, the feed horn is further shielded except for the front of the dish. The reflector can be either solid, grid or mesh screen, depending on the frequency used. The higher the frequency, the tighter the tolerance must be in dish construction. As long as the opening in the material is less than 0.01 wavelengths, it appears as a solid. Vandalism can be a problem because parabolics present attractive

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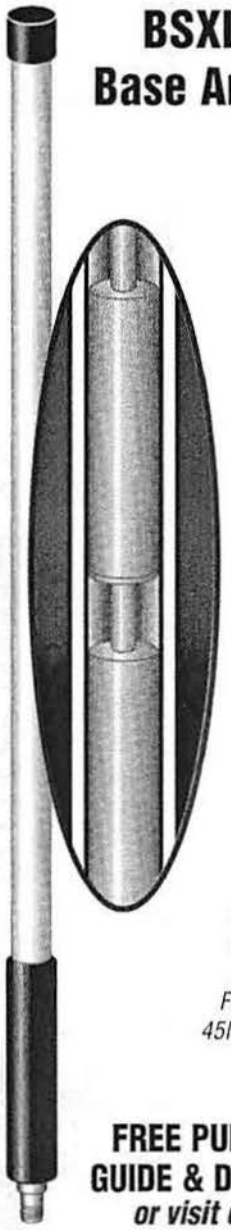

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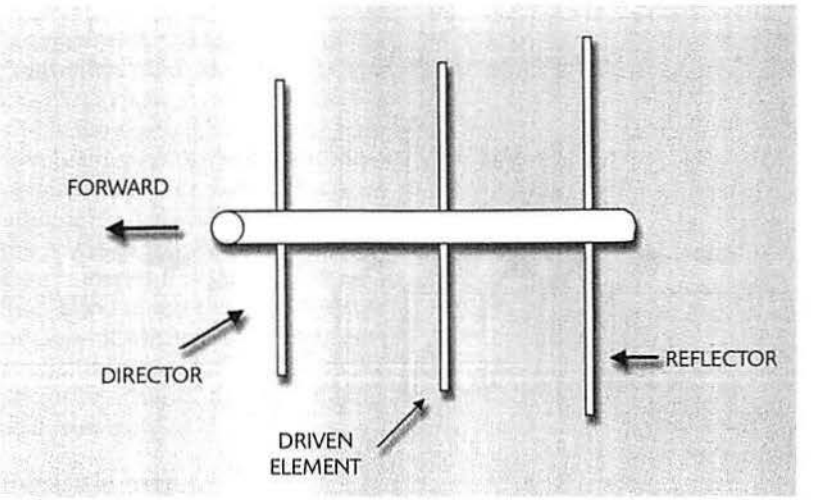


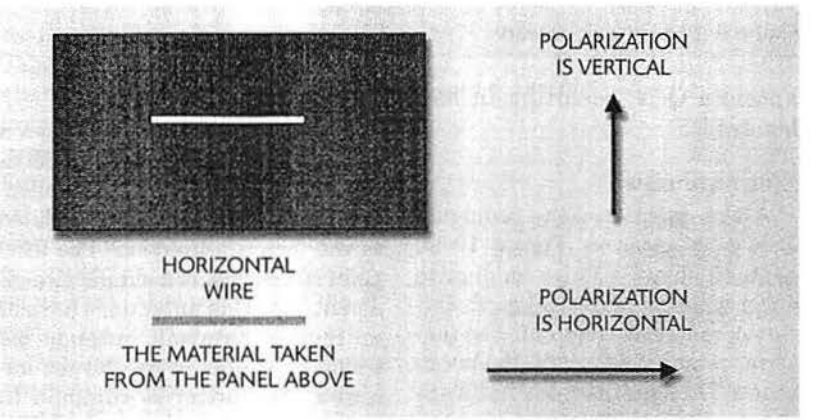


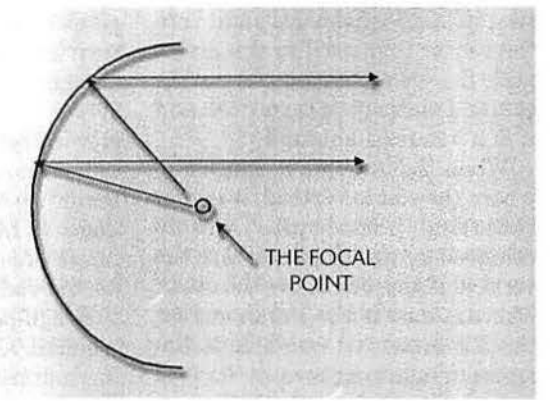


Figure 9 (top). Yagi-Uda antenna. Figure 10 (middle). The slot antenna has polarity opposite that of the wire. Figure 11 (right). The focal point is where all energy is reflected to. It is a narrow area and is easily missed by damage, often caused by leverage on the rear of the antenna such as waveguide.

targets. At 6GHz, bullet holes contribute little distortion. It's when the feed horn or waveguide is hit that the problem becomes serious. An example is a shipboard radar antenna. Most are constructed of metal screen to reduce wind loading with little reduction in either gain or beam width. Along that line, most navigational radar antennas have little material vertical but large in the horizontal. The large horizontal focuses the beam to be narrow in the horizontal and large in the vertical. This not only allows accurate bearing measurements but also allows the vessel to rock about vertically and not lose its target. A pencil beam is required for pinpoint accuracy such as fire control radar or speed measuring devices. ■

Part I of "How's Your Antenna" appeared in the August 2001 issue of *Mobile Radio Technology.*